

High Bandwidth, Multi Mode Fiber Systems

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Why Multi Mode Fiber Systems at 10 Gb / s ?

- **Backward compatibility** with previous LAN standards (FDDI, Ethernet, ATM) and sources (LED, VCSELs, FP Lasers)
- Extend the existing **lowest cost solution** with minimal changes
- Uniform solution from 10 Mb / s to 10 Gb / s for **in building applications**



Systems within buildings, How far?

- Previous surveys have shown that 300 m links cover the great majority of building interconnects
- Previous successful Gb Ethernet solutions run for less than 300m (220 m at 0.85 μm)
- Standards (and especially initial objectives) define the minimal system requirements, vendors improve to differentiate and cover niche markets



Objective: **300 m MMF links for building links.**



Multi Mode fiber solutions

Three approaches have been proposed for ~10 Gb / s multi mode fiber optic links:

- Serial solution at 0.85 μm on **new** MMF
- Coarse WDM at 1.3 μm over **”any”** fiber
- Serial solution using multi level coding over **”any”** fiber



What do they have in common ?

Use of “single” mode sources over MMF

- Serial solution over new MMF
Chromatic Dispersion => “Single mode” VCSELs
- WDM solution
Temperature stability => “Single mode” DFBs
- Multi level coding
Linearity and noise => Single mode lasers



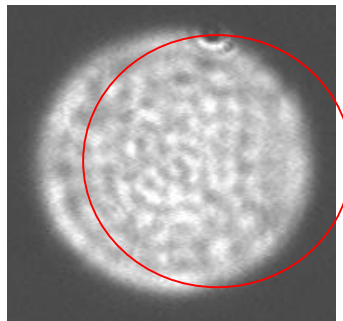
Modal Noise

Key ingredients to generate modal noise are:

Coherent sources => “Single mode” sources

Multi path links => Multi mode fibers

Spatial filtering => Lossy connectors



Fraction of coupled
power is time dependent

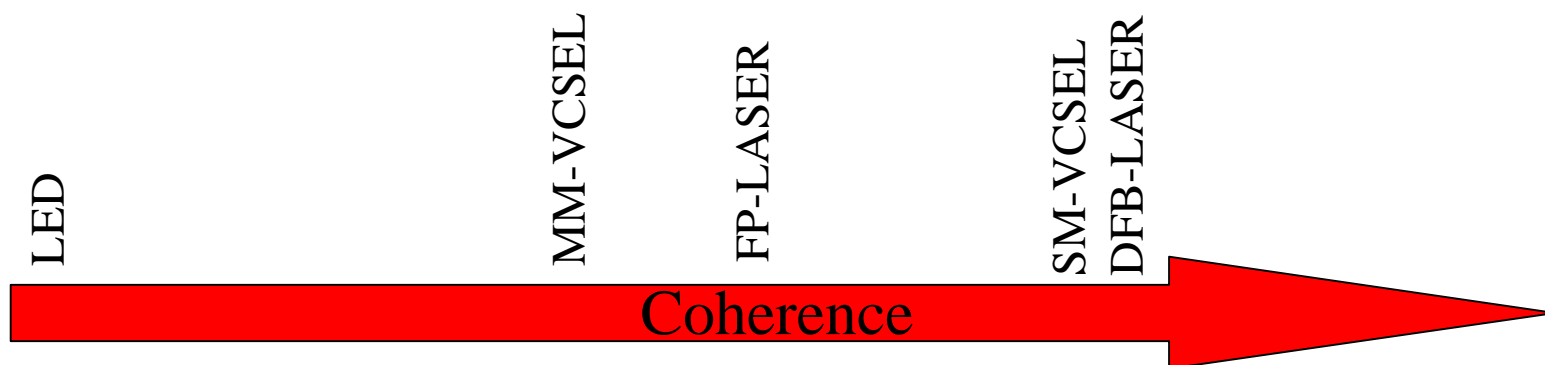


Noise



Not a problem in the past, why now?

- All the sources for Gb Ethernet were “multi mode sources” → Low coherence
 - VCSELs had multi spatial modes
 - FP sources had multi longitudinal modes



What to do about it?

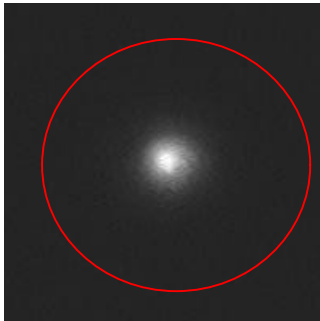
- Extensive publications exist that confirm the seriousness of the problem
 - Bates et al., IBM Watson Research Center, “Improved multi mode fiber link.....”, Opt.Quan.Elect. 1995.
 - Cunningham et al., HP Labs, “Modal noise penalties ...”, Elect.Letters 95.
- Some general solutions have been proposed but are expensive and unpractical
 - out of band modulation (100 GHz ??)
 - self pulsating lasers (100 GHz ??)



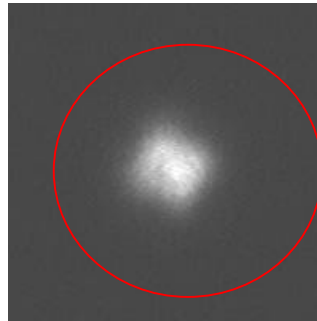
Restricted center launch

- Restricted center launch can be used to mitigate modal noise in a system through reduced loss

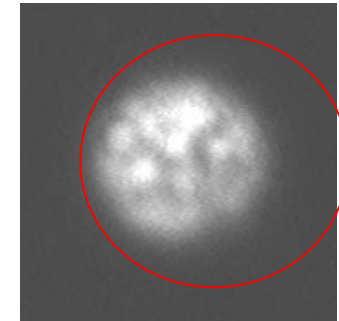
First connector



Second connector



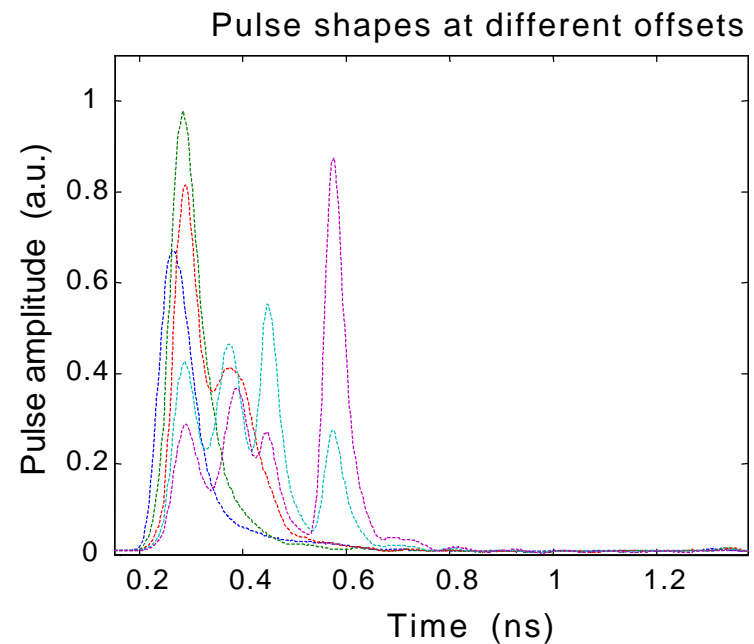
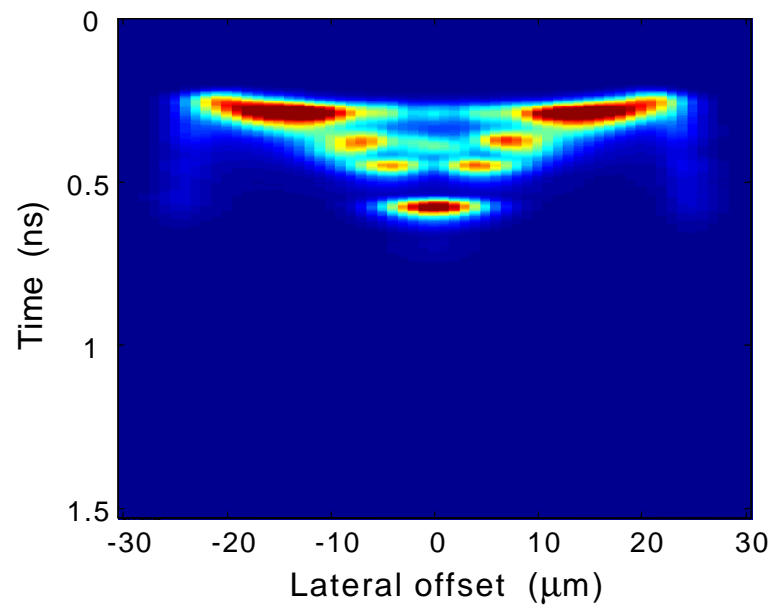
Third connector



- Requires new fiber with high restricted launch bandwidth close to the center
- Not applicable if overfilled launch is needed




Traditional MMF



- The traditional MMF can not support robust 10Gb/s transmission

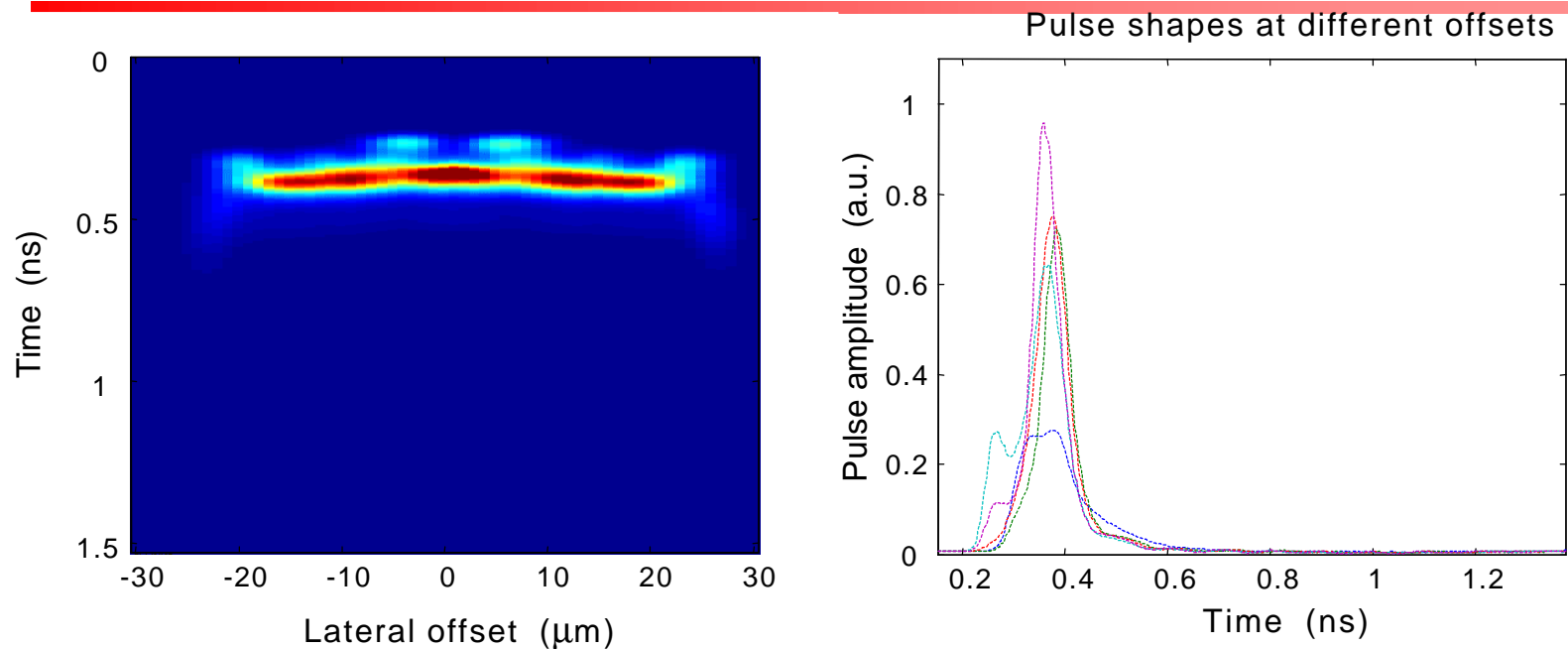


Installed base MMF systems

- Coarse WDM (and multi level coding) require **single mode tolerances** if they have to run on “any” fiber
 - Coarse WDM (and multi level coding) systems as proposed today require **offset patch cords** to run on installed MMF
 - Modal noise can not be mitigated in high bit rate systems using restricted center launch on installed MMF
- 
- Further investigation is needed to show robust transmission on installed MMF at 10 Gb / s



ZETA multi-mode fiber



- ZETA Multimode fiber has a flat and narrow DMD



Advantages of the MM serial approach

- Simple evolutionary extension, of current least expensive Gb Ethernet solution made possible from improvements in fiber manufacturing and speed advancements of electronics and receivers
- Backward compatibility with previous LAN standards (FDDI, Ethernet, ATM) and sources (LED, VCSELs, FP Lasers)
- Less expensive than SM serial due to the larger tolerances in alignment and simplified source packaging
- Less expensive than WDM since it does not require optical multiplexing and de-multiplexing, wavelength control, single mode tolerances (“any” fiber solution), and higher reliability.



System requirements for 300m MMF solution at 0.85 μ m

- Dispersion

- Modal



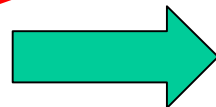
New high bandwidth fiber (ZETA)
($>2.2\text{GHz km}$)

- Chromatic

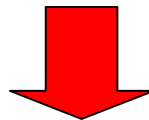


Single mode VCSELs ($<0.2\text{nm}$)

- Modal Noise



“Center” restricted launch

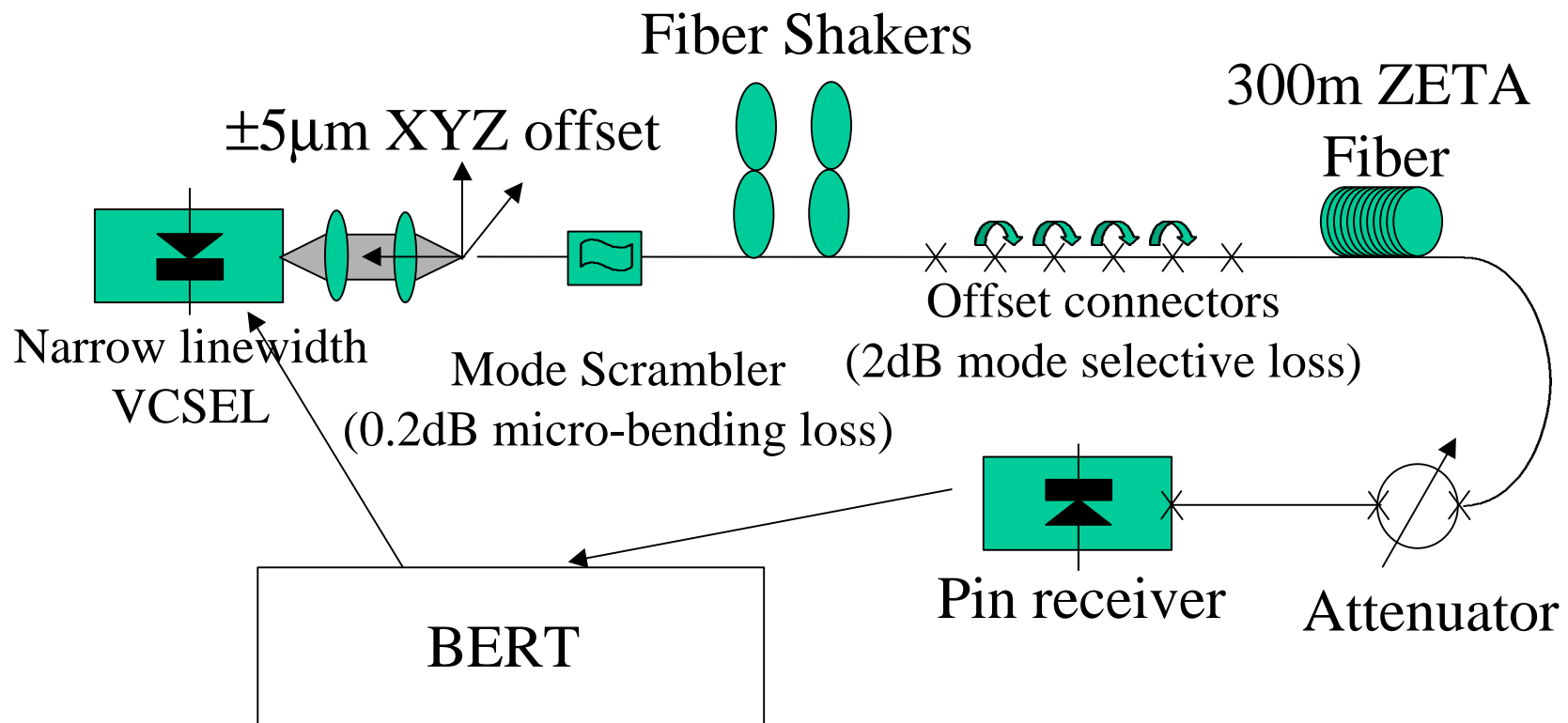


Fiber with flat and narrow DMD around the center of the fiber



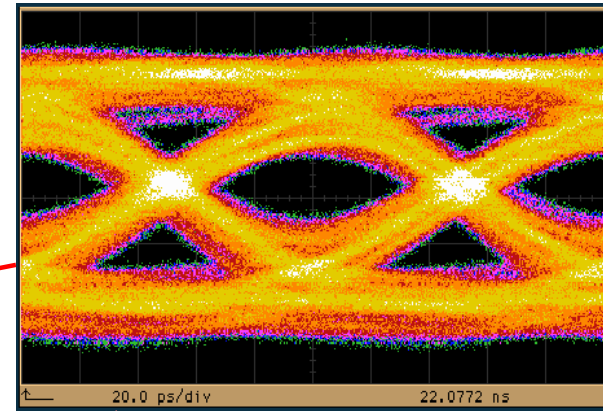
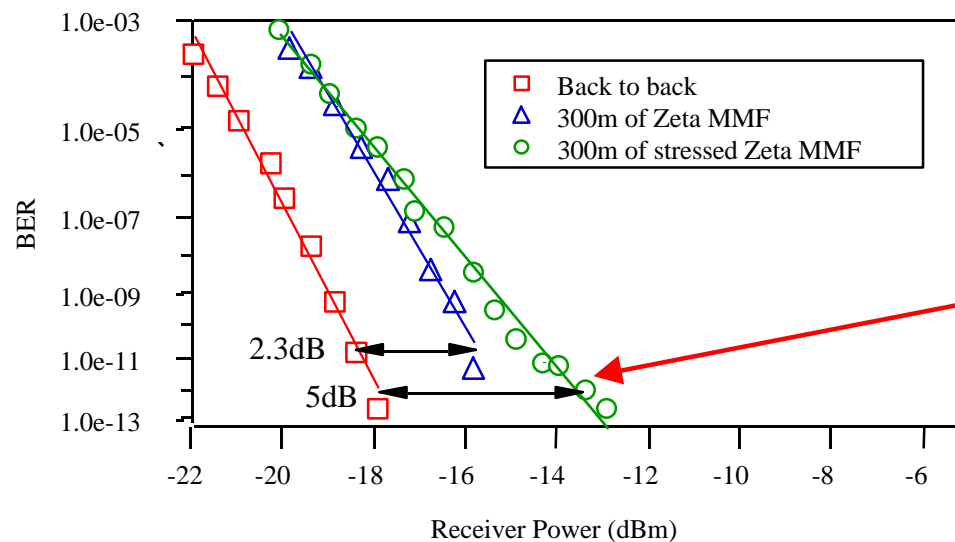
ZETA

stressed system configuration



ZETA

stressed system demonstration

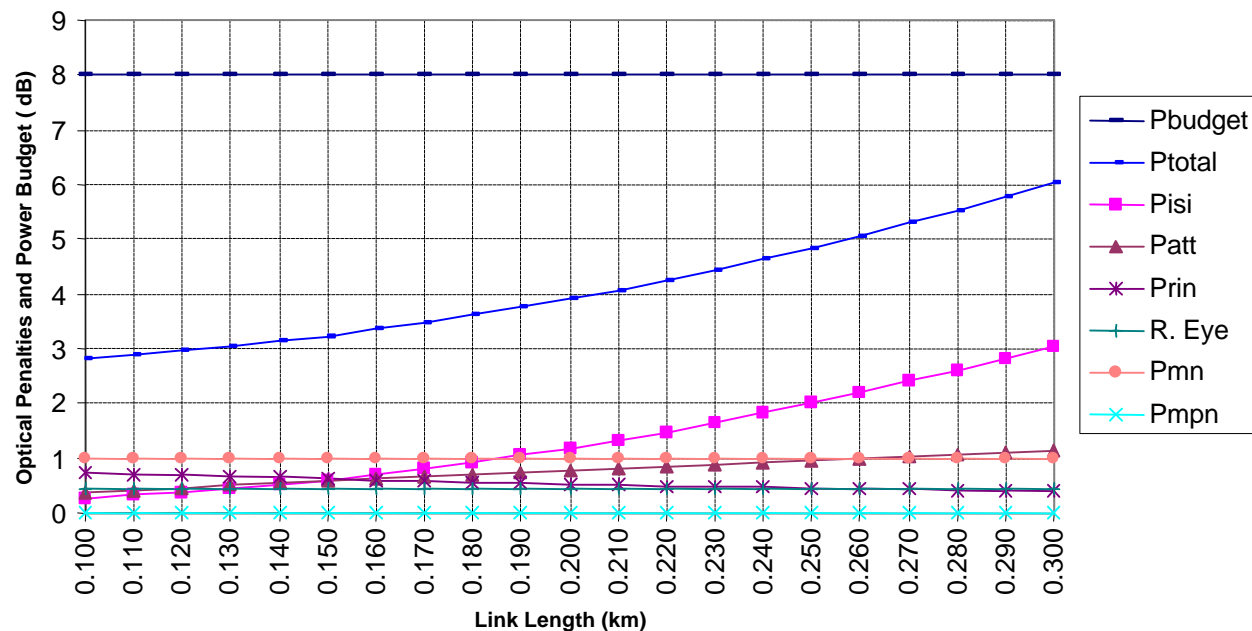


- ZETA fiber can support robust 10 Gb/s transmission even under stressed conditions



10 Gb / s Ethernet power budget

(12.5 Gbauds at 0.85 μ m)



- Minor modifications to the power budget compared to 1 Gb/s Ethernet



Options to accommodate the power budget

The 8dB power budget can be accommodated without significant cost increases using either:

- more sensitive receivers (-16,-18dBm)
- Increased eye safety limits (-1.5dBm)
- More strict laser source power control (4.3dB)
- Forward Error Correction Coding
- Open loop fiber control



Conclusions

- Modal bandwidth and Modal noise can be very serious problems for MMF solutions that don't rely on a **new fiber** design specifically tailored to mitigate them
- Objectives mentioning explicitly installed MMF are premature since modal noise issues have not been sufficiently studied (published experimental evidence supports the existence and seriousness of such problems)
- The new MMF serial solution has been demonstrated:
 - to be robust at 10 Gb / s over 300 m (Lucent Technologies)
 - to operate at 10 Gb / s over 400 m (Lucent Technologies, Gore Photonics)
 - to operate at 12.5 Gb / s over 300 m (Lucent Technologies, Gore Photonics)

